Machinability Study of AISI 316 Grade Austenitic Stainless Steel Using P 30 Grade Cemented Carbide Insert

Thesis submitted in partial fulfilment of the requirements for the Degree of

B. Tech.

In

Mechanical Engineering

By

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Dr. S.GANGOPADHYAY

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CERTIFICATE

This is to certify that the thesis entitled *Machinability Study of AISI 316 Grade Austenitic Stainless Steel using P 30 Grade Cemented Carbide Insert* submitted by Sri Sanjib Kumar Hansda has been carried out under my supervision in partial fulfilment of the requirements for the Degree of Bachelor of Technology (B.Tech.) in Mechanical Engineering at National Institute of Technology, NIT Rourkela, and this work has not been submitted elsewhere before for any other academic degree/diploma.

However, experimental part reported here has been jointly conducted by Sri Sanjib Kumar Hansda and Ajit Soreng.

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ABSTRACT

Austenitic stainless steel is one of the most important engineering materials with wide variety of applications. Superior resistance to corrosion and compatibility in high temperature and high vacuum have particularly made it an attractive choice. However, the machinability of austenitic stainless steel is not very promising owing to lower thermal conductivity, higher degree of ductility and work hardenability

Grade 316 is the standard molybdenum-bearing grade. Molybdenum gives 316 better corrosion resistance properties than crevice corrosion in chloride environment. It has excellent forming and welding characteristics.

Over the years, cemented carbide (WC-Co) has overcome many drawbacks of high speed steel (HSS) as cutting tool materials and become one of the most versatile cutting tool materials during machining both ferrous and non ferrous alloys. There are mainly three grades of cemented carbide cutting tools i.e. K, P and M grades. Steel being very ductile in nature produces long, continuous chips during machining. Moreover, iron in steel has greater affinity towards carbon of WC of the tool. P grade, is more diffusion resistant grade due to presence of more stable carbides like TiC, TaC and NbC. Therefore, P grade is also known as mixed carbide grade and more suitable for machining steel.

Since P 30 grade of cemented carbide would provide excellent balance of hardness, wear resistance and toughness, the same grade has been chosen for machining of stainless steel. In the first phase of work, tool life test would be carried out using three different cutting velocities i.e. 100, 150 and 200 m/min with constant feed of 0.2 mm/rev and constant depth of cut of 1 mm for different duration of machining. Tool life study would be based on average flank wear, VB= 0.3 mm criterion. Flank wear would be measured using a stereo zoom optical microscope. Therefore, effect of cutting speed on tool life of uncoated P30 grade carbide insert would be studied during dry machining of 316 grade of austenitic stainless steel. Also effect of cutting speed on various chip characteristics during machining of austenitic stainless steel was studied. The different chip characteristic include types of chips, colour of chips, micro and macro morphology of chips, chip thickness and chip reduction coefficient.

CHAPTER 1

INTRODUCTION

1. STAINLESS STEEL

Stainless steel, are also known as corrosion-resistant steel, because it is an iron-based steel alloy, which contain minimum 11% chromium. Chromium present in it prevents it from getting corroded. When ordinary carbon steel is exposed to rain water, it corrodes easily due to formation of a brown iron oxide on the surface, which is commonly called as rust. But when more than about 10% chromium is added to ordinary steel, the oxide on the surface is transformed. Stainless Steel generally has high ductility, weldability and cryogenic toughness properties.

Stainless steel differs from carbon steel by the amount of chromium present. When exposed to air and moisture unprotected carbon steel rusts easily. This iron oxide film (the rust) is active and accelerates corrosion by forming more iron oxide.

1.1. Properties

Two important physical properties are thermal conductivity and thermal expansion rate. Type 304 is the common austenitic stainless steels, which have lower thermal conductivity than carbon steels. Their rate of thermal expansion is also greater than ordinary steel, so care must be taken during welding to ensure that the recommended jigging and tacking procedures and welding sequences are followed.

For most corrosion resistant applications, strength is not a key issue. There are exceptions, such as pressure vessels. A characteristic of the austenitic stainless steels is that their strength increases rapidly when they are formed at ambient temperatures, such as in rolling or wire drawing operations

1.2. MACHINABILITY OF STAINLESS STEEL

Machinability is the term used to denote the machining performance of a material by a cutting tool. The ease with which a given material may be worked with a cutting tool is machinability. Machinability depends on :

(a) Chemical composition of job material

(b) Structure

(c) Mechanical properties

(d) Physical properties

(e) Cutting conditions

The criteria for judging machinability may be :

(a) Tool life

(b) Cutting force

(c) Surface finish

(d) Chip characteristic (Chip colour, chip types, chip thickness, chip reduction coefficient)

(e) Cutting temperature

When compared with carbon steels due to their difference in properties, slightly different techniques are required when machining stainless steels. The carbon content of steel greatly affects its machinability. High-carbon steels are very difficult to machine because they are strong and they contain carbides which abrade the cutting tool. Low-carbon steels are "gummy" and stick to the cutting tool, resulting in a built up edge that shortens tool life.

Therefore, steel has the best machinability with medium amounts of carbon, about 0.20%. Chromium, molybdenum and other alloying metals are often added to steel to improve its strength. However, most of these metals also decrease machinability.

Inclusions in steel, especially oxides, may abrade the cutting tool. Machinable steel should be free of these oxides.

Stainless steels have poor machinability compared to regular carbon steel because they are tougher, gummier and tend to work harden very rapidly. We can decrease its gumminess and make it easier to cut by slightly hardening the steel.

1.2.1. Need for machining Stainless Steel

One of the major advantages of the stainless steels is their ability to be fabricated by all the standard fabrication techniques. The common austenitic grades can be folded, deep drawn, bent, cold and hot forged, spun and roll formed. As the material is of high strength and very high work hardening rate all of these operations require more force than for carbon steels, so a heavier machine may be needed. Austenitic stainless steels also have very high ductility, hence capable of being very heavily cold formed, although they have high strengths and high work hardening rates, into items such as deep drawn laundry troughs, few other metals are capable of achieving this degree of deformation without splitting.

1.2.2. DIFFERENT TYPES OF STAINLESS STEEL

Stainless Steels are usually classified into four categories depending on their primary constituent of the matrix :

1. ***Martensitic stainless steels***

It is a high carbon containing steel, having a higher carbon level (nearly 1%) and 18% chromium. Martensitic stainless steel contains chromium (18%), molybdenum (0.2–1%), nickel (less than 2%), and carbon (about 0.1–1%) giving it more hardness but making the material a bit more brittle. Presence of nickel and molybdenum increases its strength. Martensitic stainless steel can be easily hardened by subjecting it to heat, and it is also highly resistant to abrasion, though it displays less resistance to corrosion compared to other alloys of stainless steel. It has poor weldability and is magnetic. It displays magnetic properties and is used in the manufacture of surgical instruments, valves, knife blades, etc. Increasing hardness typically reduces tool life and machinability. Increasing the carbon content the proportion of abrasive chromium carbides in the matrix increases and reduces tool life and machinability.

2. ***Ferritic stainless steels***

These are plain chromium stainless steels with varying chromium content between 11% and 18%, but with low carbon content. Ferritic alloys are generally more machinable than other alloys. Their machinability generally decreases with increasing chromium content. They have a moderate to good corrosion resistance, are not hardenable by heat treatment and always used in the unhealed conditions. They are magnetic. The formability is not as good as the austenitic. These are commonly used in computer floopy disk hubs , automotive trim , automotive exhausts , material handling equipment and in hot water tanks.

3. ***Austenitic stainless steels***

Most commonly used austenitic stainless steel contain 18% chromium and 8% nickel. They have an excellent corrosion resistance, weldability, formability fabricability, ductility, cleanability and hygiene characteristics. Along with good high and excellent low temperature properties, these are non magnetic (if annealed) and are hardenable by cold work only.

4. ***Duplex stainless steels***

These are stainless steels contining relatively high chromium (between 18 and 28%) and moderate amounts of nickel (between 4.5 and 8%). The nickel content is insufficient to generate a fully austenitic structure and the resulting combination of ferritic and austenitic structures is called duplex. Most duplex steels contain molybdenum in a range of 2.5 - 4%. These also have a high resistance to stress corrosion, cracking and chloride ion attacks. They have a higher tensile and yield strength than austenitic of ferritic steels as well as good weldability and formability. They are commonly used in marine applications, desalination plants, heat exchangers and petrochemical plants.

1.2.3. Composition of different types of Stainless Steel

1. Martensitic stainless steels

Type 410 : a 13% chrome, 0.15% carbon alloy possessing good ductility and corrosion resistance. It can be easily forged and machined.

Type 416 : similar to 410 but has added sulphur giving improved machinability

Type 431 : a 17% chrome, $2^{1/2}$ % nickel 0.15% max carbon stainless alloy.has superior corrosion resistance to type 410 and 416 due to nickel. Usually supplied in bar form.

2. *Ferritic stainless steels*

Type 430 : a 17% chrome, low alloy ferritic steel. It has good corrosion resistance properties up to about 800^0C. Used in strip and sheet form due to its poor machinability.

3. *Austenitic stainless steels*

Type 304 : Excellent corrosion resistance in unpolluted and fresh water environment. Contain 18% chrome and 8% nickel.

Type 321 : a variation of type 304 with Ti added in proportion to the carbon content. Type 347 : uses Niobium instead of Ti

Type 316 : addition of 2-3% molybdenum gives increased corrosion resistance in off shore environments

Type 317 : similar to 316 but the 3-4% molybdenum gives increased pitting resistance when immersed in cold sea water.

4. *Duplex stainless steels*

UNS S31803 : composition is 0.03% max. Carbon, 122% Cr, 5.5% Ni, 3% Mo and 0.15% N

UNS S32304 : Typical composition is 0.03% max. Carbon, 23% Cr, 4% Ni

and 0.1% N

UNS S32750 : Composition is 0.03% max. Carbon, 25% Cr, 7% Ni, 4% Mo and 0.28% N

1.2.4. Advantages and Applications of Austenitic Stainless Steel

Austenitic steels have austenite as their primary phase (face centered cubic crystal). These are alloys containing chromium and nickel (sometimes manganese and nitrogen. Austenitic steels are not hardenable by heat treatment. The most familiar stainless steel is Type 304, which is sometimes called T304 or simply 304. Type 304 surgical stainless steel is an austenitic steel containing 18-20% chromium and 8-10% nickel. Compared to typical carbon steel, Austenitic stainless steel have high ductility, low yield stress and relatively high ultimate tensile strength.

. A carbon steel on cooling transforms from Austenite to a mixture of ferrite and cementite. In austenitic stainless steel, the presence of high chrome and nickel content suppress this transformation by keeping the material fully austenite on cooling. Heat treatment and the thermal cycle caused by welding, have no influence on mechanical properties. Strength and hardness can be increased by cold working, which will also reduce ductility.

Austenitic steel has good corrosion resistance and excellent high-temperature tensile and creep strength, but still severe corrosion can occur in certain environments

Applications :

- It is used for chemical processing equipment, for food, dairy, and beverage industries, for heat exchangers, and for the milder chemicals.
- Used mostly in the pulp and paper industry.
- Often used in stacks which contain scrubbers
- Sometime used in boat fitting
- Woven or welded screens are used for mining, quarrying and water filtration
- Sometimes with thread fasteners and springs are also used

1.3. CHALLENGES IN MACHINING STAINLESS STEEL

Austenitic Stainless Steel are distinguished by their suitable applicative nature due to their good combination of high chemical properties. These properties are dependent and influenced by quantity and nature of their alloying elements. They are also dependent on the heat treatment used. The major challenges while machining are expressed in high adhesion affinity up to high cutting speed ranges, high thermal loads as well as in a hardening of the material. Further the high toughness leads to an unpropitious chip breakage and increased burr formation. In turning stainless steel, burr formation is of great importance because it influence not only the quality and handling of work piece but also the tool wear.

1.4. GRADES OF STAINLESS STEEL

Stainless steel grades are iron alloys that contain more than 10.5% of chromium. To amplify its properties other alloys are added to the stainless steel. The grading is based on the metallurgical structure and nature of stainless steel.

Grade 304 is the standard "18/8" stainless; it is the most versatile and most widely used stainless steel, available in a various range of products, forms and finishes. It has excellent forming and welding characteristics.

Grade 316 is the standard molybdenum bearing grade. Molybdenum gives 316 better overall corrosion resistant properties than grade 304. It has excellent forming and welding characteristics. It is readily brake or roll formed into a varity of parts.

Grade 316L, the low carbon version of 316 and is immune from sensitisation (grain bounding carbide precipitation). Thus, extensively used in heavy gauge welded component (over about 6mm).

Grade 316H, with its higher carbon content has application at elevated temperature.

Possible alternative grades to 316 stainless steel :

316Ti – Better resistance to temperature of around 600-900 ^{0}C is needed

316N – Higher strength than standard 316

317L - It have higher resistance to chlorides than 316L, but with similar resistance to stress, corrosion cracking

904L – Much higher resistance to chlorides at elevated temperatures, with good formability

220S – Much higher resistance to chlorides at elevated temperatures and higher strength than 316

1.4.1. Engineering Applications of different grades of Stainless Steel

Type 301 : Trains, aircraft, belt conveyors, vehicles, bolt, springs

Type 304 : Sink, interior piping, hot water machine, bathtub, boiler, automobiles parts

Type 304L : Machinery & tools used in the chemical, coal & petroleum industry that require high inter granular corrosion resistance, building material, heat resistance parts and parts that are difficult to treat after fabrication

Type 316 : material for use in sea-water, equipment for manufacturing dye,paper, acetic acid, fertilizer and chemicals, in the photo industry, food industry, the facilities constructed in the coastal area, bolts and nuts

Type 316L : especially welded products, made with 316 steel that require superior intra granular corrosion resistance

Type 321 : airplane exhaust pipe, boiler cover, bellow & hoses

Type 409L : exhaust pipe, heat exchanger, container, etc.

Type 430 : heat resistance tools, burner, household electric appliance parts, sink cover, building material, bolts, nuts

1.4.2. Difference between 304 and 316 of Stainless Steel

Type 304 is the most common austenitic grades, containing normally, 20% chromium and 10 % nickel, combined with a maximum of 0.08 % carbon. While type 316 contains 16% to 18% chromium and 11% to 14% nickel. 316 has molybdenum added to the nickel and chrome of the 304. Carbon contain is 0.03 % .

The main difference is that 316 contains 2% - 3% molybdenum and 304 has no molybdenum. The "moly" is added to improve the corrosion resistance to chlorides.

Type 304 is used for chemical possessing equipment, for food, for dairy, for heat exchangers, and for the milder chemicals. While Type 316 is used in chemical processing, in the pulp and paper industry, for food and beverage processing and dispensing.

In the marine environment, where strength and wear resistance are needed, and type 304 being slightly higher strength and wear resistance than type 316 it is used for nuts, bolts and screws.

1.4.3. Advantages of 316 over 304

Type 316 stainless steel has molybdenum, which gives it more corrosion resistance than type 304 stainless steel. In chlorine environment, 316 stainless steel offers a high resistance to crevice corrosion and pitting than 304 stainless steel.

Type 316 stainless steel is often used in heavy gauge welding applications because the risk of pitting, cracking and corrosion is reduced, while type 304 stainless steel often used in the creation of cookware and in the construction of dairy equipment, such as milking machines.

1.5. CUTTING TOOL MATERIAL

A cutting tool is any tool that is used to remove material from the workpiece by means of shear deformation. Cutting may be single-point or multipoint tools. Single-point tools are used in turning, shaping, plaining and similar operation. Milling and drilling tools are often multipoint tools.

1.5.1. Different cutting tool materials

1. High Speed Steel

High speed steel (HSS) is a high carbon ferrous alloy consisting of W, Mo, Cr, V, and Co. HSS is generally available in cast, wrought and sintered (obtained by using powder metallurgy technique) form. HSS is inexpensive compared to other tool materials. It is easily shaped, and has excellent fracture toughness, and fatigue resistance. HSS is suitable for use only at limited cutting velocities of 30-50 m/min because of its limited wear resistance and chemical stability. HSS is generally used for geometrically complex rotary cutting tools such as drills, reamers, taps, and end-mills, as well as for broaches. HSS are broadly classified as

T-type steels which have tungsten as the dominant alloying element, and M-type steels in which the primary alloying element is molybdenum.

2. Cemented carbide

Cemented carbide is a modern cutting tool material manufactured by mixing, compacting and sintering primarily tungsten carbide (WC) and cobalt (Co) powders. Co acts as a binder for the hard WC grains. The carbide tool have strong metallic characteristics having good electrical and thermal conductivity. They are chemically more stable, have high stiffness and exhibit lower friction, and operate at higher cutting velocities than HSS tools. But carbide tools are more brittle and more expensive than HSS. They are generally recommended for machining steel. K grade carbides are straight tungsten carbide grades with no alloying carbides. They are used for machining grey cast iron, nonferrous metals, and nonmetallic materials. M grade carbides are alloyed WC grades generally with less amount of TiC than the corresponding P series, and have wider application in machining austenitic stainless steel, manganese steel as well as steel castings. Each grade within a group is assigned a number to represent its position from maximum hardness to maximum toughness (higher the number, tougher the tool). P grades are rated from P01 to P50, M grades from M10 to M40, and K grades from K01 to K40. The performance of carbide cutting tool is dependent on the percentage of Co and grain size of carbide(s).

3. Cermets

Cermets are ceramic materials in a metal binder. They consist of TiC, TiN, or TiCN hard particles held together by a softer binder alloy of Co and/or Ni, Mo. Cermets are less susceptible to diffusion wear than WC, and have more favourable frictional characteristics. Cermet cutting tools are most suitable for the machining of steels, cast irons, cast steels and nonferrous free-machining alloys because they are capable of operating at higher cutting velocities than cemented carbides thus allowing better surface finish. However, they have a lower resistance to fracture and lower thermal conductivity, and are more feed sensitive.

4. Ceramics

Ceramics are inorganic, nonmetallic materials that are subjected to high temperature during synthesis or use. They retain excellent hardness and stiffness at temperature greater than 1000 °C, and do not react chemically with most work materials at these temperatures. There are two main categories of commercially available ceramic tools:

- Alumina-based ceramics comprising of pure oxide, mixed oxides, and silicon carbide (SiC) whisker reinforced alumina ceramics.
- Silicon nitride-based ceramics.

1.6. <u>Different Engineering Applications</u> :

- As food preparation equipment particularly in chloride environment
- Laboratory benches and equipment
- Coastal architecture panelling, railing and trim
- Boat fitting
- Chemical containers including for transport
- Heat exchanger
- Woven or welded screens for mining, quarrying and water filtration
- Thread fasteners

CHAPTER 2

LITERATURE REVIEW

2. *Machinability Study of Stainless Steel*

2.1. *Effect of Machining Parameters on Cutting Force*

According to Ciftci(2005) AISI 316 resulted in higher forces at all cutting speeds employed than AISI 304. The 2.0% Mo present in AISI 316 was considered to be the cause of the higher forces. Zhuang et al.(2010) studied two steel, free cutting austenitic stainless steel and austenite stainless steel 1Crl8Ni9Ti at various cutting speeds ,they find that the cutting forces generally decreased with the increase of cutting speed in the range 10 - 80 m/min. They reached 418 N and 336 N at 10 m/min cutting speed for steel A and B, respectively. And at 80 m/min cutting speed, principal forces were 343 N and 275 N for steel A and B, respectively. S.Agarwal et al. Measured both the axial and the tangential components of the cutting force during turning. The chips were also collected for examination of their under-surface and top surfaces in SEM. The cutting edges of the coated tools were examined in SEM to determine the extent of wear.

2.2. *Effect of Machining Parameters on Tool Life*

2.2.1. *Influence of the Cutting Speed and Feed Rate*

Tekiner et al.(2003) studied the values of flank wear resulting from five different cutting speeds 120, 135, 150, 165 and 180 m/min and three different feed rates 0.2, 0.25 and 0.3 mm/rev, flank wear is decreasing while feed rate is rising from 0.2 to 0.25 mm/rev; and then it is starting to increase when it is rising 0.3 mm/rev. Built up edge values forming on insert used in different cutting parameter were measured by microscope, by doing this, it was seen that cutting speed increased and built up edge value decreased. Astakhov

(2006) showed that the tool life decreases with increasing cutting feed. According to Korkut et al.(2003) Tool flank wear decreased with increasing the cutting speed up to 180 m/min. According to Akasawa et al. (2003) copper addition reduced the amount of adhering material on the tool face. It is usually easy in steel-making processes to add copper to steel and copper is known to reduce strain hardening, thus it has the potential to improve machinability. But because copper may accelerate the wear of K-grade carbide tools through copper diffusion into the binder of carbides, it is important to select the optimum carbide tool grade.

2.2.2. *Influence of the Depth of Cut*

Astakhov (2006) showed that when the depth of cut increases and the uncut chip thickness is kept the same, then the chip compression ratio and the average contact temperature remain unchanged. Hence, any change in increase in the depth of cut would not change the tool wear rate. The depth of cut has very little influence on the tool wear rate when the cutting speed was determined to be optimal for the depth of cut d_w = 0.5 mm.

2.2.3. *Influence of the Work piece Diameter*

As discussed by Astakhov (2006), the diameter affects the static and dynamic rigidity of the machining system, curvature of the surface being cut, and interaction of the thermal and deformation waves in the layer being removed.

2.3. *Effect of Machining Parameters on Surface Finish*

According to Tekiner et al. (2003) the lowest average value of surface roughness got obtained at 150 m/min cutting speed. Surface roughness values obtained from at 165 and 180 m/min cutting speeds were little higher than the one obtained from at 150 m/min and, if the surface roughness quality is important, feed rate should not be higher than 0.25 mm/rev. Akasawa et al. (2003) Carried out machining tests with dry and with a cutting fluid, Yushiro BZ574 (5 l/min) on an NC lathe using K10 carbide tools (TH10). Wet cutting was done on a feed rate of 0.05 mm/rev for 25 min. After turning for 2, 4, 8, 16 and 25 min, the width of the corner wear land, VC, and top wear, N, of the tools were measured. Top wear is the retreat of the highest top of the tool measured from the highest point of the original corner in a direction perpendicular to the working plane. As a cutting action was done solely in the corner area of the tools, the tool corner wear land and top wear were the most important factors affecting the surface finish and the dimensional accuracy of work pieces. Also explained that as the cutting speed increased, the defects decresed and as a result surface roughness improved. According to Korkut et al.(2003) Surface roughness values were found to decrease with the increasing cutting speed. This can be attributed to the presence of built-up-edge at the lower cutting speeds. According to Ibrahim Ciftci (2005) Cutting speed was found to have a significant effect on the machined surface roughness values. With increasing cutting speed, surface roughness values decreased until a minimum value was reached, beyond which they increased. Higher surface roughness values at lower cutting speeds were attributed to the high BUE formation tendency. Chipping of the cutting edges, evidenced by the SEM examinations, was also found to be responsible for the high surface roughness values.

2.4. *Objective of present work*

From the literature review it has been though some research wok was under taken in to study the influence of machining parameters on various aspects of machinability of austenitic stainless steel, still there exits some gap which need to be studied in more detail. There is no report of systematic study of influence of machining parameters on tool life and various chip characteristics of 316 grade austenitic stainless steel keeping them in mind, the objective of the present work has been formulated as follows :

(i) To study the performance or effectiveness of ISO P30 grade cemented carbide insert in dry machining of austenitic stainless steel.

(ii) To study the influence of cutting speed on average flank wear for different duration of machining at constant feed and depth of cut

(iii) To study the effect of cutting speed on various chip characteristics during machining of austenitic stainless steel. The different chip characteristics include types and colour of chips, micro and macro morphology of chips, chip thickness and chip reduction coefficient.

CHAPTER 3

EXPERIMENTAL METHODS AND CONDITIONS

3.1. *Setup for Turning State*

The turning experiments were carried out using uncoated cemented carbide inserts in a HMT NH26 lathe machine. The grades and composition of the turning inserts (Make: Widia) have been provided in Table 2. The machining trials were performed with three cutting speeds (V_c) 100, 150, and 200 m/min with a constant feed (f) of 0.2 mm/rev and a depth of cut of (t)1 mm under dry environment. The tool holder used for machining is ISO SSBR 2020K12 (Kennametal, India).

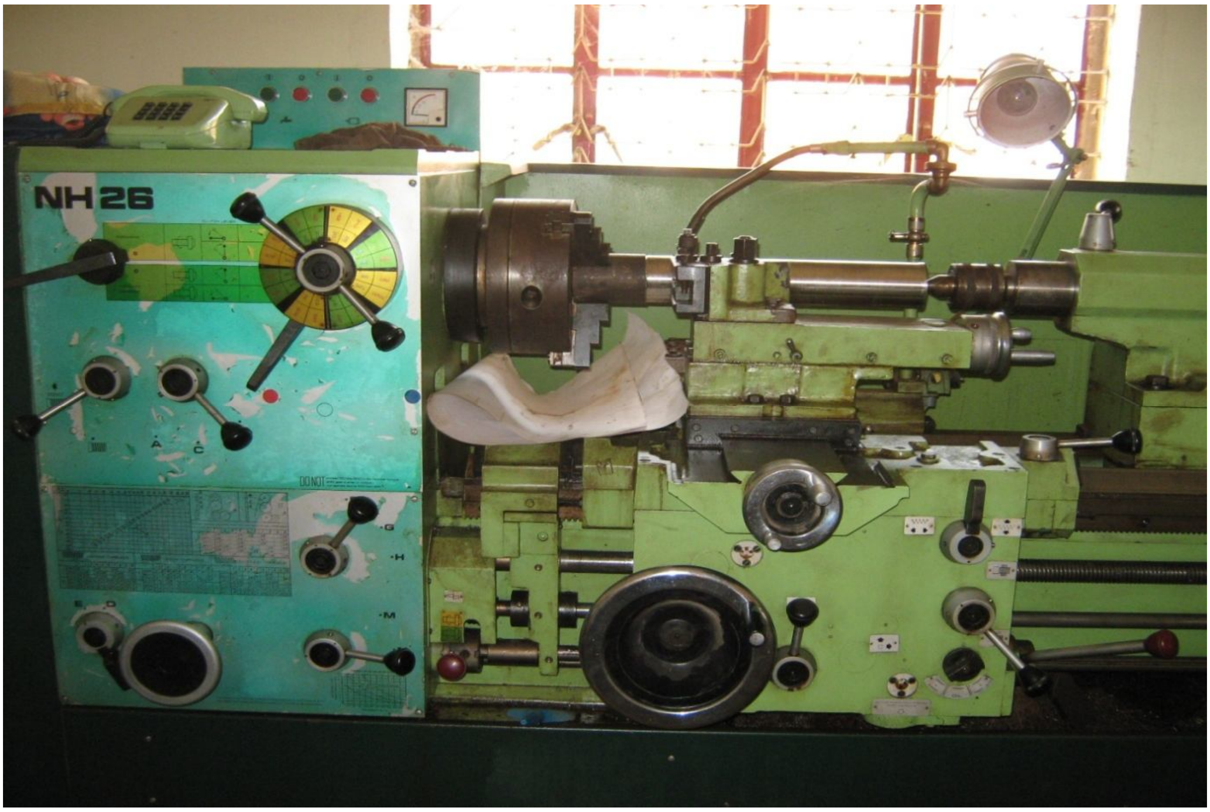


Fig.1. Experimental set up for dry turning of AISI 316 grade austenitic stainless steel

Table 1. Experimental Conditions for Turning

Workpiece material	AISI 316 steel
Inserts used	Uncoated cemented carbide insert (ISO p30 grade, WC-6%Co),
Insert designation	SCMT 12 04 08
Tool geometry	−6°, −6°, 6°, 6°, 15°, 75°, 0.8 (mm)
Cutting velocity (m/min)	100,150,200
Feed (mm/rev)	0.2
Depth of cut (mm)	1
Environment	Dry

3.2. *Description of cutting tool*

Tool Designation

SCMT 12 04 08

S - Insert Shape = 90^o

C – Clearance Angle = 7^o

M – Medium Tolerance = +/- 0.005"

T – Insert Features (Counter sinking hole with chip groove on top surface for easy flow of chip over rake surface)

12 – 12 means length of each cutting edge is 12 mm

04 – 04 stands for nominal thickness of the insert is 4 mm

08 – 08 stands for nose radius = 0.8 mm

Table 2. Tool Designation

S.N	Cutting Tool	ISO Grade and Specification	Composition
1	Uncoated Cemented carbide insert	P30 SCMT120408	WC-Co+TiC+TaC

3.3. *Designation Tool Holder*

ISO SSBR 2020K12 (Kennametal, India)

3.4. *Work Piece Detail*

AISI 316 grade austenitic stainless steel. AISI 316 contains 16% to 18% chromium and 11% to 14% nickel. 316 has molybdenum added to the nickel and chrome of the 304. AISI 316 stainless steel has molybdenum, which gives it more corrosion resistance. Type 316 stainless steel is often used in heavy gauge welding applications because the risk of pitting, cracking and corrosion is reduced.

Work piece of 600 mm length and 80 mm diameter was taken initially for turning operation.

3.4.1. *Composition*

Table 3. Composition of different elements present in AISI 316

Element	C	Mn	Si	P	S	Cr	Mo	Ni	N
Wt. %	0.08	2.0	0.75	0.045	0.03	18.0	3.00	14.00	0.10

3.4.2. *Properties*

Table 4. Mechanical properties of AISI 316 grade stainless steels.

Tensile strength (MPa) (min)	Yield Stress 0.2% of (MPa) (min)	Stress Elongation Proof (%50mm) (min)	Hardness in Rockwell B (HR B) (max)	Brinell Hardness (max)
515	205	40	95	217

3.4.3. *Applications*

Materials for use in sea water, equipments for manufacturing chemicals, paper, dye, acetic acid and fertilizer, food industry, the facilities constructed in the coastal area, rope, CD bar, bolts, nuts.

3.5. *DESCRIPTION OF EXPERIMENT*

Since P30 grade of cemented carbide would provide excellent balance of hardness, wear resistance and toughness, the same grade has been chosen for machining of stainless steel. In the first phase of work, tool life test would be carried out using three different cutting velocities, i.e. 100,150 and 200 m/min with constant feed of 0.2 m/rev and constant depth of cut of 1 mm at dry condition. Tool life study would be based on average flank wear, VB = 0.3 mm criterion. Flank wear would b measured using stereo zoom optical microscope.

First machining was done at a speed of 100m/min with constant feed 0.2 mm/rev and constant depth of cut 1mm for 60s. Then carbide insert was cleaned with the help of aqueous 20 % H_2SO_4 solution and then through acetone inside a beaker containing H_2SO_4 for 15 min., then sample is viewed in stereo optical microscope. Photograph of rake surface and flank surface were taken. Average flank wear value was measured with the help of image analyser software (Calipro), then the turning was continued for another 60s using the same cutting edge as the previous one and also under same machining condition and the process was repeated till average flank wear reaches 0.3 mm. Once tool life was reached a fresh cutting edge of same insert was used for V_c = 150 m/min, so this way process was continued for V_c = 200 m/min also. This way the progression of tool wear with machining duration for different cutting velocity (100, 150, 200 m/mm) was studied.

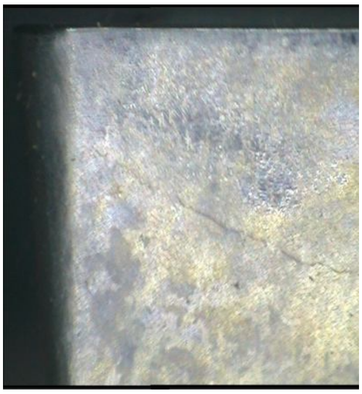
Chips were also collected for each turning trial. All the chips were characterised by types and colour of the chip, chip thickness, chip reduction coefficient and chip radius.

Macro morphology of chip was studied using digital camera and stereo zoom optical microscope. The micro morphology was studied using SEM. Chip thickness was calculated by digital vernier calliper and chip radius was measured using optical microscope coupled with image analyser (Calipro). The Condition of the tool inserts before and after machining was also studied using SEM.

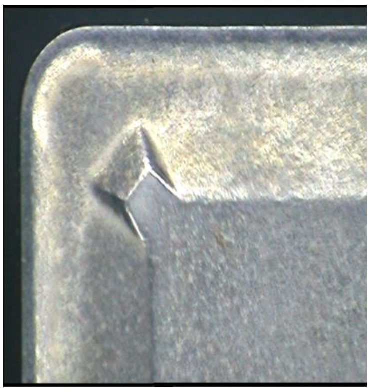
CHAPTER 4

RESULTS AND DISCUSSION

4.1. CONDITION OF UNCOATED TOOL BEFORE MACHINING



(a)

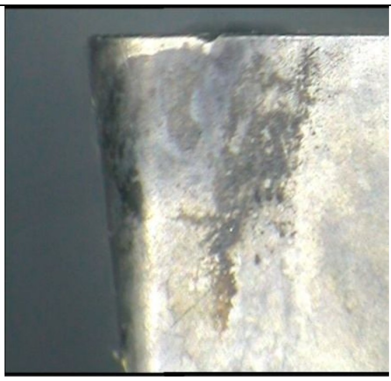
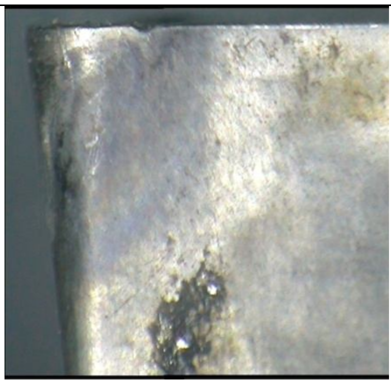


(b)

(c)

Fig. 2. Optical microscope photo of uncoated tool before machining (a) Flank surface; (b) Rake surface; (c) Carbide tool

4.2. *TOOL WEAR*

V_c = 100 m/min,f=0.2mm/rev,t=1mm			
SL.NO.	MACHINING DURATION (sec)	RAKE SURFACE	FLANK SURFACE
1	60		
2	120		
3	180		

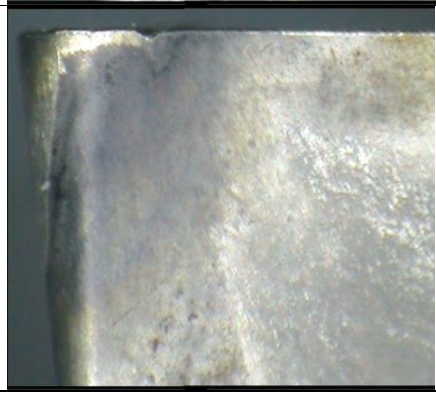
SL.NO.	MACHINING DURATION (s)	RAKE SURFACE	FLANK SURFACE
4	240		
5	300		
6	360		

Fig 3..Optical Microscope photo of rake face and flank face at Vc =100m/min on different machining duration

Fig 3. Shows the condition of rake and flank surface of the uncoated tool after machining AISI 316 austenitic Stainless Steel with cutting velocity V_c = 100 m/min observed at different time interval every after 60s. Upto 180s there is no vital change in flank surface, after 240s there is little wear at the flank surface and it increases gradually. It is also observed that the condition of rake surface was not adversely affected as the turning operation progressed. The adverse flank wear condition and the chipping of the nose may be attributed to the work hardening and the low thermal conductivity characteristic of the austenitic stainless steel.

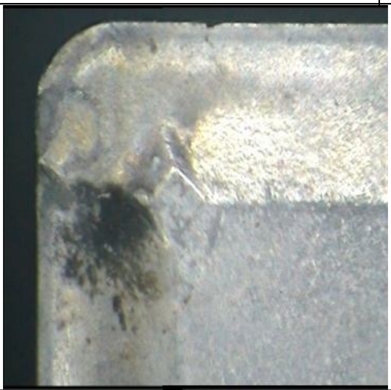
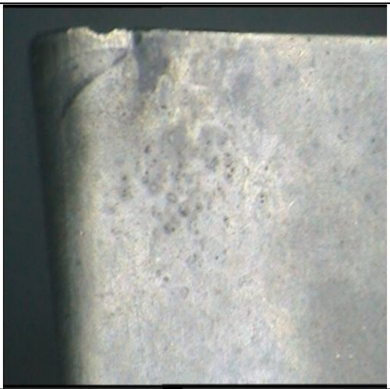
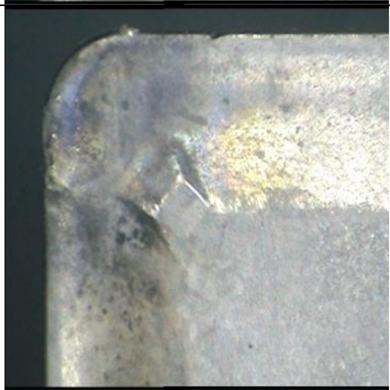
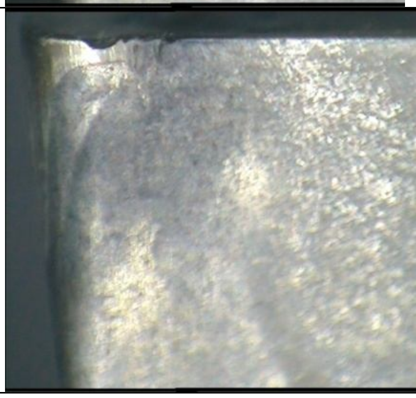
V_c= 150 m/min ,f=0.2mm/rev,t=1mm			
SL.NO.	MACHINING DURATION (s)	RAKE SURFACE	FLANK SURFACE
1	60		
2	120		
3	180		
4	240		

Fig 4. Optical Microscope photo of rake face and flank face at Vc =150m/min on different machining duration

Fig 4. shows the condition of rake and flank surface of the uncoated tool after machining AISI 316 austenitic Stainless Steel with cutting velocity V_c = 150 m/min observed at different time interval every after 60s. The observation was taken upto 240s. After 60s there was greater flank wear was observed but after 120s and 180s flank wear remains almost same, there is no adverse effect on flank surface . After 240s again there was increase in flank wear. Here also condition of rake surface was not adversely affected as the turning operation progressed.

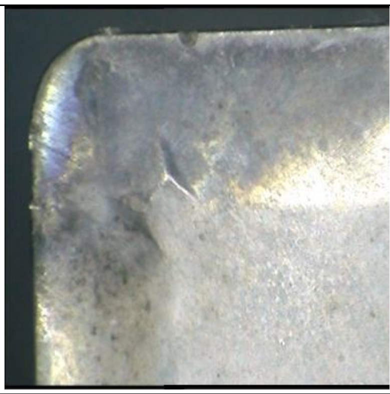
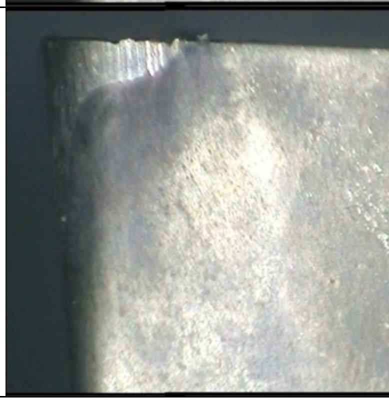
V_c=200 m/min, f=0.2mm/rev,t=1mm			
SL.NO.	MACHINING DURATION (s)	RAKE SURFACE	FLANK SURFACE
1	60		
2	120		

Fig 5. Optical Microscope photo of rake face and flank face at Vc =200m/min on different machining duration

Fig 5. shows the condition of rake and flank surface of the uncoated tool after machining AISI 316 austenitic Stainless Steel with cutting velocity V_c = 200 m/min observed after 60s and 120s of machining. After 60s there was little change in flank wear but after 120s flank wear increased gradually. There was little wear at the rake surface after 120s.

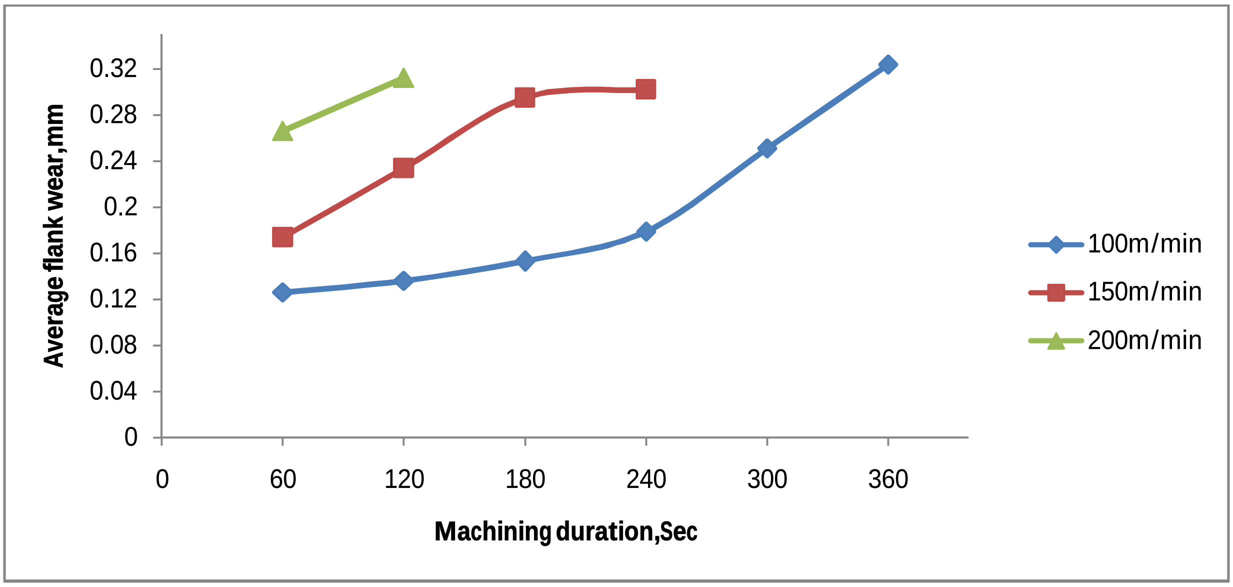
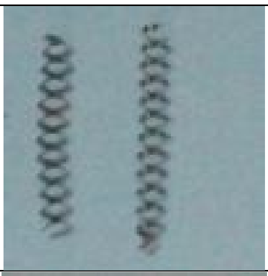
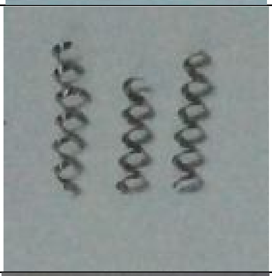


Fig 6. Effect of cutting speed and maching duration on average flank wear

Condition of rake and flank surface of the uncoated tool after machining AISI 316 austenitic Stainless Steel with different machining duration for different cutting velocity (i.e. V_c = 100,150 1nd 200 m/min) was shown in Fig1, Fig 2 and Fig 3 respectively. It is observed that the condition of rake surface was not adversely affected as the turning operation progressed. It was then observed that there was chipping at the nose of the trol insert when machining was carried out at V_c =200 m/min. The fig.6. also shows that flank wear for different cutting velocity and it clearly demonstrates cutting speed has significant influence on flank wear while dry machining of 316 grade austenitic stainless steel. Progression of machining at different cutting speed has been represented graphically in Fig. 6. So it is evident from fig.4 that as the cutting speed increased, the average flank wear also increased. The adverse flank wear condition and the chipping of the nose may be attributed to the work hardening and the low thermal conductivity characteristic of the austenitic stainless steel. So it may be concluded that it is not suitable to machine 316 grade austenitic stainless steel under dry condition with a cutting speed 200 m/min

4.3. Study of Chip Characteristic

Table 5. Macro morphology of chip obtained at different cutting speed

Duration (s)	Cutting Speed (m/min)	Photograph of Chips
60	100	
120		
180		

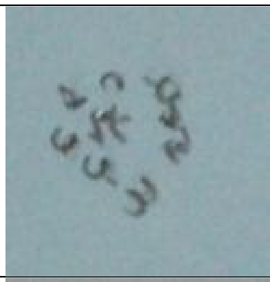
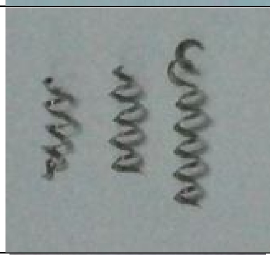
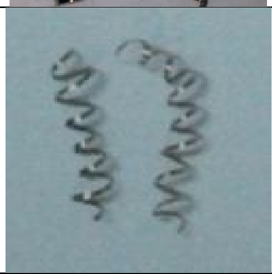
Duration (s)	Cutting Speed (m/min)	Photograph of Chips
60	150	
120		
180		
60	200	
120		
180		

Table 6.Chip Characteristic at V_c=100 m/min

Duration	Types of Chips	Colour of the Chip	Chip Thickness	Chip Reduction Coefficient (ζ)
60s	Continous	Yellow	0.48	2.49
120s	Continous	Yellow	0.4833	2.50
180s	Continous	Yellow	0.4933	2.55

Table 6. shows the characteristic of chip at V_c=100m/min at different machining duration (i.e. 60s, 120s and 180s). In all time duration continuous chips were out and colour of chips at different time duration remains same i.e. yellow. It was observed that chip thickness increases gradually with increase in time duration. It was also observed that chip curl increases with increase in machining duration.

Table 7. Chip Characteristic at V_c=150 m/min

Duration	Types of Chips	Colour of the Chip	Chip Thickness	Chip Reduction Coefficient (ζ)
60s	Discontinous	Yellow	0.4166	2.16
120s	Discontinous	Yellow	0.433	2.24
180s	Discontinous	Yellow	0.446	2.31

Table 7. shows the characteristic of chip at V_c=150m/min at different time duration. Here in all time duration discontinuous chips were out and colour of chips at different time duration also remains same i.e. yellow. It was also observed that chip thickness increases with increase in time duration. Also chip curl increases with increase in machining duration.

Table 8. Chip Characteristic at V_c=200 m/min

Duration	Types of Chips	Colour of the Chip	Chip Thickness	Chip Reduction Coefficient (ζ)
60s	Continous	Yellow	0.40	2.07
120s	Continous	Yellow	0.403	2.09
180s	Continous	Yellow	0.426	2.21

Table 8. shows the characteristic of chip at V_c=200m/min at different time duration. In all machining duration continuous chips were found and colour of chips at different time duration remains same i.e. yellow. Here also it was observed that chip thickness increases with increase in time duration. With increase in machining duration chip curl increases.

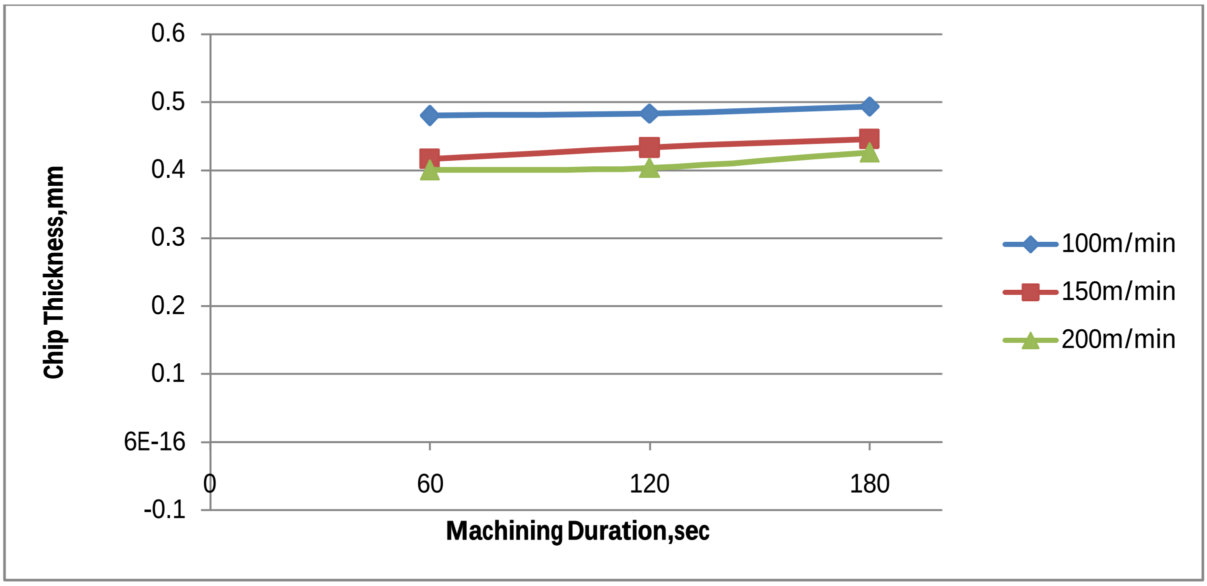


Fig.7.Effect of chip thickness on cutting speed

Fig 7. shows the effect of chip thickness on different cutting speed. At V_c=100 m/min chip thickness increases as the duration increases, similarly V_c=150 m/min and V_c=200 m/min chip thickness increases with the increase in machining duration. It was observed that chip thickness decreases as cutting speed increases. While chip thickness increases after every 60s time interval at same cutting speed.

CHAPTER 5

CONCLUSION

From the present investigation following conclusions may be drawn :

(i) Cutting speed has significant influence on growth or progression of flank wear. Rapid tool wear took place at high cutting speed (V_c = 200 m/min) where, systematic growth of tool wear was observed for V_c = 100 m/min and V_c = 150 m/min

(ii) As the cutting speed increased average flank wear also increased for a particular machining duration

(iii) Cutting speed also has important effect on various chip characteristics. When cutting speed increased, chip thickness and chip reduction coefficient decreased. Hence, colour of the chips has all along been yellow. Thin and continuous chips were obtained at high cutting speed i.e. V_c = 200 m/min.

From the present study it is recommended to use cutting speed in the range of 100-150 m/min particularly when machining under dry condition

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